BBC RD 1994/1

Research and Development Report

IMPLEMENTATION OF AMPLITUDE MODULATION COMPANDING USING A DIGITAL SIGNAL PROCESSOR

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Research and Development Department,
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Summary

BBC Amplitude Modulation (AM) radio transmissions have for some time been using amplitude modulation companding (AMC) - a method of companding whose purpose is to reduce the costs of transmission whilst maintaining, as far as possible, the audibility of the radio service. AMC is one form of compression of AM transmissions more generally called dynamic carrier control (DCC). The BBC has undertaken a feasibility study to examine the possibility of implementing DCC by means of a Digital Signal Processor (DSP).

The study has shown that a DSP implementation of DCC would be entirely feasible, providing a stable and reliable means of realising the compression algorithms and the potential for greater sophistication in control

Issued under the Authority of

General Manager
Research and Development Department

Research and Development Department
Engineering Division
BRITISH BROADCASTING CORPORATION

(T-33)

1994

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1. INTRODUCTION

In AM Radio there are two radio frequency techniques regularly used to improve efficiency, amplitude modulation companding (AMC*) and dynamic amplitude modulation (DAM).

AMC is a method of companding whose purpose is to save transmission costs by instantaneously reducing the transmitted signal power during periods of high modulation. Previous work[1-4] has described AMC in detail.

In the context of HF transmitters, an additional AMC function was considered by the BBC — carrier enhancement. This is a technique which, when applied with AMC, allows the transmitted signal power to be increased during periods of low modulation and decreased during periods of high modulation, whilst still making an overall saving of transmission costs. This function requires slightly more sophisticated control of the transmitter, but results in the dual benefits of increased audibility and reduction of transmission costs.

AMC is one method of implementing a general compression technique called dynamic carrier control, or DCC. The alternative method of implementing DCC is known as dynamic amplitude modulation, or DAM. It is often convenient for transmitters to be provided with AMC and DAM as alternative control options.

Even more complex dynamic carrier control regimes could be envisaged which could assist by providing such features as control linked to transmitter temperature, or to station peak power requirements. (For example, particularly in the context of HF transmitters, a peak power demand can occur during transmission of the time signal on many different transmitters simultaneously. If a high level of compression can be applied at the instants of high modulation, a significant reduction in the stations' peak power demands may be achieved.)

At present, AMC is implemented using a mixture of analogue and digital techniques. This Report describes an investigation to test the feasibility of providing these complex compression arrangements by means of a digital signal processor (DSP) at the transmitter. The case for considering this is good, as non-DSP implementations already require digital-to-analogue and analogue-to-digital converters to provide accurate linear compression, and to delay the audio modulating signal to compensate for the delay in determining the compression factor. The DSP provides a means of implementing the compression, and also for calculating the amount of compression required.

2. THEORETICAL DESCRIPTION

A summary of the theory of the AMC and DAM systems is presented here, but more detailed descriptions may be found elsewhere[1-6]. The carrier enhancement mode of operation for AMC is also described. Section 2.3 discusses the requirements of a DSP implementation of DCC.

2.1 Description of AMC

As noted in the introduction, AM companding reduces the transmitted signal power during periods of high modulation. Fig. 1 *(overleaf)* shows the effect of AMC. Fig. 1(a) shows a small part of a modulating signal, which varies from 0 to 100% modulation. Fig. 1(b) shows the conventional double sideband AM which this signal would produce. Fig. 1(c) shows the effect of applying 6 dB of compression — the unmodulated part of the signal is unaffected, but the amplitude of the modulated part is reduced by 6 dB.

This shows an idealised situation. The compression has been switched on suddenly, whereas in practice it would be increased less abruptly. Whilst it may appear that the envelope of the signal (and hence the modulation) has been destroyed, it should be remembered that this signal is expanded again by the automatic gain control (AGC) in the receiver. Provided that the time constant used to apply the compression is larger than the time constant of the AGC circuit, the original double sideband AM signal is regenerated at the input to the demodulator. The only difference will be an increase in the level of the noise during the periods of high modulation.

The above describes the extremes of the application of compression (viz. 0% and 100% modulation), but a full range of modulation conditions

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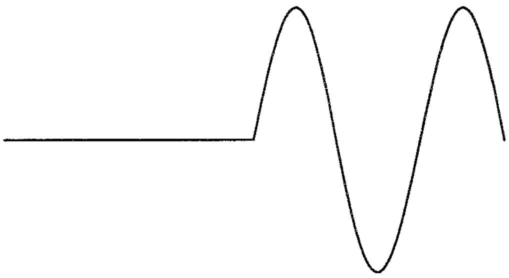
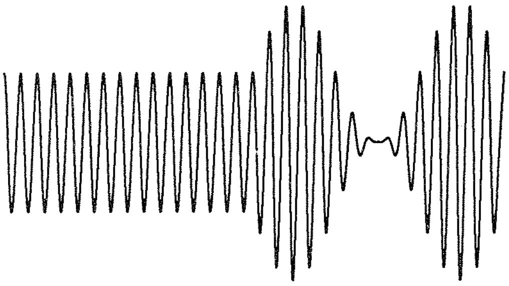
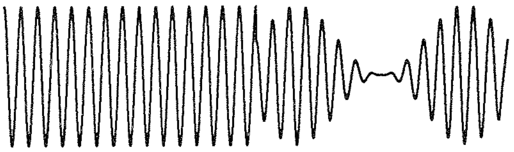
* Dynamic Carrier Control (DCC) can be implemented either as Amplitude Modulation Companding (AMC) or as Dynamic Amplitude Modulation (DAM). These terms have sometimes been confused in the past. AMC has also been known as radiation compression, and DAM as volume-dependent amplitude modulation or carrier controlled amplitude modulation.



(a) The modulating signal.



(b) The modulated RF signal without compression.



(c) The effect of the compression.

Fig. 1 - Effect of AMC on a modulated signal.

must be catered for. In general, a compression curve will be used, of the form shown in Fig. 2. This shows a cut-off point in the application of the compression (in this case 10%), below which no compression is applied. A maximum compression of 6 dB is shown for 100% modulation.

A small change to the curve of Fig. 2 allows for the carrier enhancement mode. An example of this is shown in Fig. 3. In this, the low modulation conditions are subject to an increase of transmitted power (2 dB for the curve of Fig. 3), whilst the higher modulation conditions are still compressed, although not as much as before.

The effect of this on a modulated signal can be seen in Fig. 4. Fig. 4(a) shows the conventional double sideband signal of Fig. 1(b) again, and Fig. 4(b) shows what happens when this is subject to 6 dB of compression and 2 dB of enhancement. The level of the unmodulated carrier has been increased, and the modulated part has been reduced, although not by as much as before. Note also that the peak to peak range of the signal has been reduced. Transmitters are usually limited by the peak voltage range that can be handled, as well as by the mean power level. If enhancement were applied with no compression, the peak voltage range of the transmitter would be exceeded. However, by applying both compression and enhancement simultaneously, the transmitter can be protected from excessive voltages.

The overall effect of this combined enhancement and compression regime is that, for low modulation conditions (quiet parts of the programme), the power is increased, resulting in a reduction of the noise in the receiver. At high modulations (loud parts of the programme), the power is reduced, giving an increase in the noise. Because this only occurs during loud parts of the programme, it will tend to be masked by the programme. So an improvement in overall perception of the quality of reception could be achieved, whilst still making significant savings in the amount of transmitted power.

Great care (and therefore control) needs to be exercised when operating a transmitter with

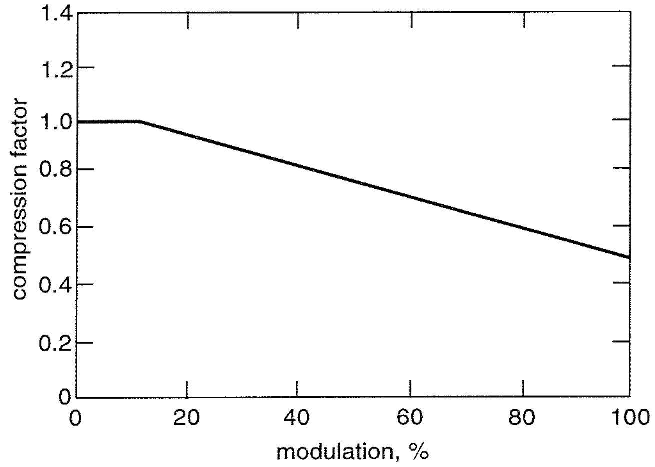


Fig. 2 - Typical AMC compression characteristic (without enhancement).

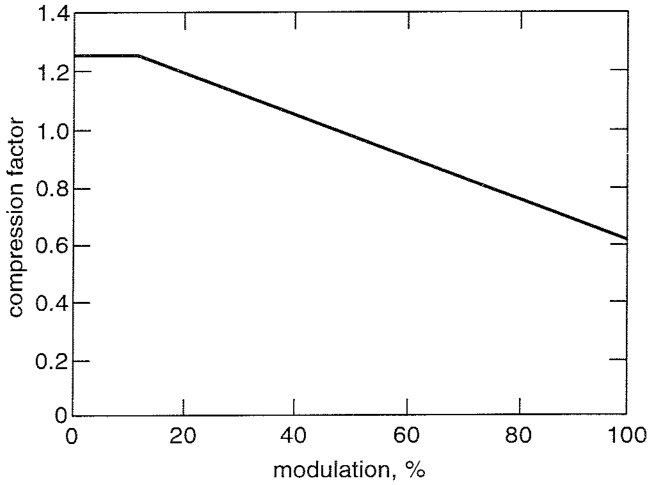
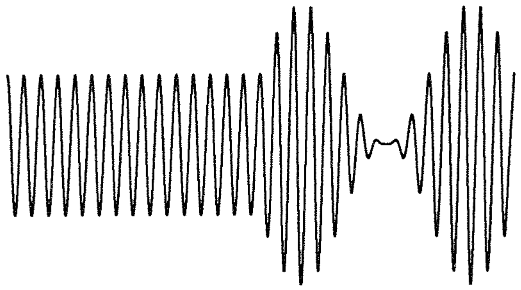
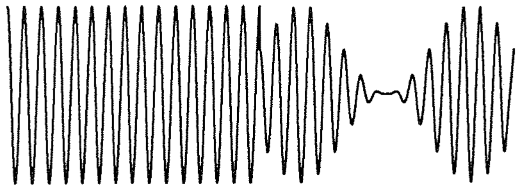


Fig. 3 - Typical AMC compression characteristic (with enhancement).



(a) The signal from Fig. 1(b).



(b) The effect of applying 2 dB of enhancement and 6 dB of compression.

Fig. 4 - Effect of AMC enhancement mode on a modulated signal.

enhancement. There is a possibility of thermal overloading, and of exceeding voltage or current limits.

The maximum level of enhancement depends on the modulation depth. If the transmitter is capable of handling continuous tone modulation at 70%, it is capable of handling a continuous power increase of 1 dB above the unmodulated case. Therefore, the maximum enhancement that could safely be applied continuously would be 1 dB. Of course, if the depth of modulation is high, the mean power will be reduced below the level of the unmodulated case by the compression. If more than 1 dB of enhancement is used, fine control of the transmitter will be needed. Whilst the input signal level is high, it is safe to apply the enhancement, but if there is little or no modulation, for a period of say 1 or 2 minutes, it would be necessary to remove the enhancement entirely for a short time. Alternatively, the application of the enhancement mode could be linked to the transmitter's temperature. If the temperature of the transmitter was found to be rising above a pre-set level because of the application of the enhancement, the enhancement could be steadily reduced until the temperature had stabilised.

A feature of the AMC system is that, no matter what compression or enhancement is applied to the signal, the depth of modulation remains the same. Therefore, it is important in its implementation that any compression applied to the audio signal must be applied identically to the carrier component.

2.2 Description of DAM

The alternative method of implementing DCC is dynamic amplitude modulation, or DAM. This operates in a different fashion from AMC, as it is only the carrier component of the signal that is varied (the sideband components are left unaltered). The underlying philosophy for DAM is that it is the carrier component which is wasteful of energy, because it carries no information and yet, in conventional AM it accounts for between 66.7% and 100% of the transmitted power. In DAM, when the input signal is less than 100%, the carrier amplitude may be reduced according to a pre-determined characteristic; Fig. 5 shows examples of this. These are described in more detail below. The reduction of carrier amplitude results in an increase of the depth of modulation, which will tend to make the received programme sound louder. In addition, the received signal will have undergone greater amplification in the receiver's AGC circuitry (because of the reduced carrier level). It is, in fact, this amplification which will make the received signal sound louder. The noise and interference added to the signal during transmission will have been amplified by the same amount as the signal though, so the signal-to-noise ratio will be the same with or without DAM.

The DAM process is illustrated in Fig. 6 *(overleaf)*. Fig. 6(a) shows a sample of the carrier modulated to a depth of 75%. Fig. 6(b) shows this signal after application of the basic DAM characteristic. Note that the depth of modulation has been increased to 100%. Fig. 6(c) shows this signal amplified by the receiver AGC to restore the average carrier level, maintaining the modulation depth at 100%.

Since the depth of modulation has changed differently for different parts of the programme, according to the chosen DAM characteristic, the programme will inevitably suffer distortion. However,

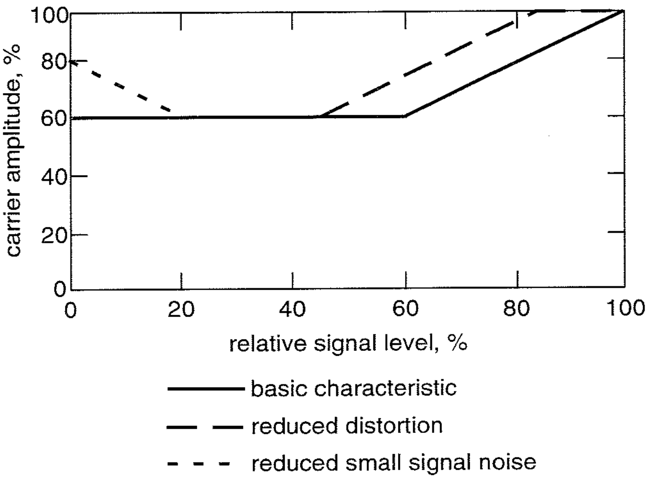
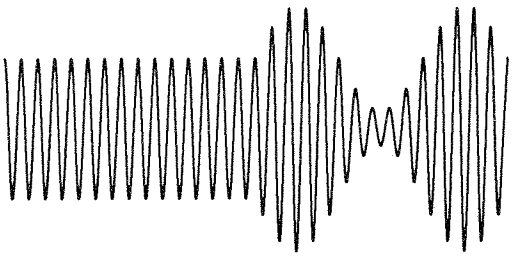
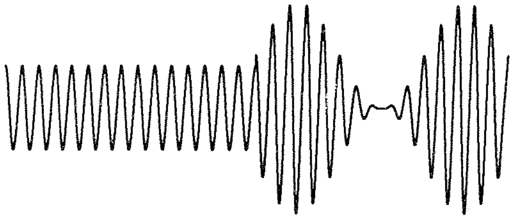


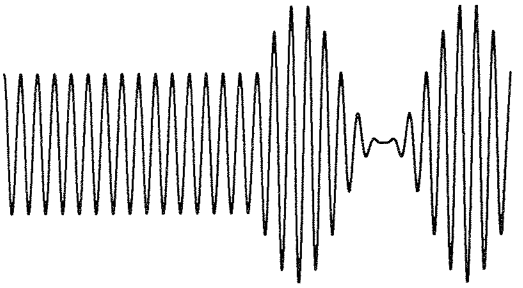
Fig. 5 - Examples of typical DAM control characteristics.



(a) Modulated carrier.



(b) Modulated carrier after application of DAM.



(c) Effect of receiver AGC on the transmitted signal.

Fig. 6 - Effect of DAM on a modulated carrier.

it has been found that the effect of this distortion in most receivers is almost imperceptible.

Three examples of possible control characteristics are shown in Fig. 5, and the rationale behind these merits some further explanation. The first curve is the most basic form of DAM, with the carrier level being reduced by a fixed amount for small signals (up to 60% in this case), and then increasing linearly above this. This results in the depth of modulation being 100% for any input signal larger than 60%, as shown in Fig. 7. The severe nature of this compression can result in noticeable distortion, but this can be improved considerably by using the second curve of Fig. 5. This results in the improved modulation characteristic as shown in Fig. 7. The final improvement which can be made is to use a smaller carrier reduction in the case of small signals. Although in principle the signal-to-noise ratio remains the same under the application of DAM, during programme pauses, the noise will be more apparent because of the increased amplifying action of the receiver's AGC. To overcome this, the DAM characteristic can be raised for small signals as shown in Fig. 5. The corresponding modulation curve is shown in Fig. 7.

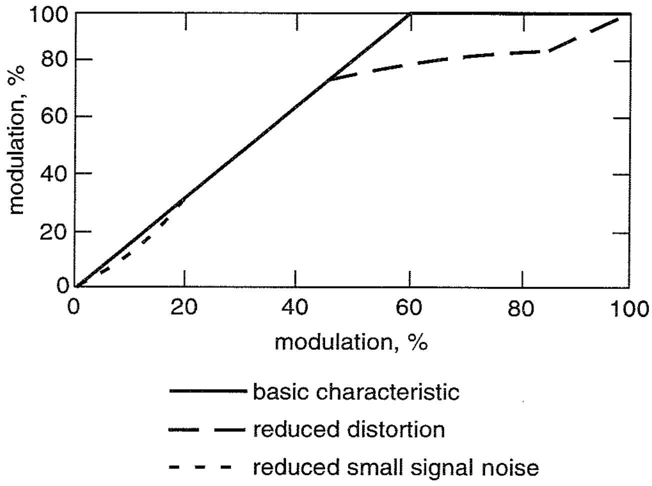


Fig. 7 - Depth of modulation for the DAM control characteristics of Fig. 5.

2.3 Implementation

Previous implementations of AMC[7] have relied on a hybrid approach — the control signal is generated by analogue means, but the delay and compression of the audio signal itself has been achieved by digitising the audio. This approach limits the flexibility of the system.

An alternative means of generating the necessary signals and retaining flexibility of operation, would be to use a DSP to apply the compression and generate the control signals. The DSP can carry out the necessary mathematical computations on the digitised audio signal in real time.

The block diagram, giving the basic functions required of the DSP to implement AMC, is shown in Fig. 8, and for DAM in Fig. 9. Note that the control signal in both of these is used to drive the carrier level of the transmitter.

In addition to being used to implement DCC, it is possible that the DSP could alternatively be used to implement single sideband modulation, other types of compression, pre-correction for transmitter non-linearities or perhaps even the addition of data signals. These possibilities have not as yet been explored further.

The DSP could also be used to determine other real time characteristics of the audio signal. For example, if enhancement is used with AMC, a careful measure of the modulation may be required. This could be achieved by adding a side branch to the block diagram of Fig. 8, to perform a long term averaging of the audio. This information would be used in turn to determine whether any change was required to the combination of enhancement and compression settings.

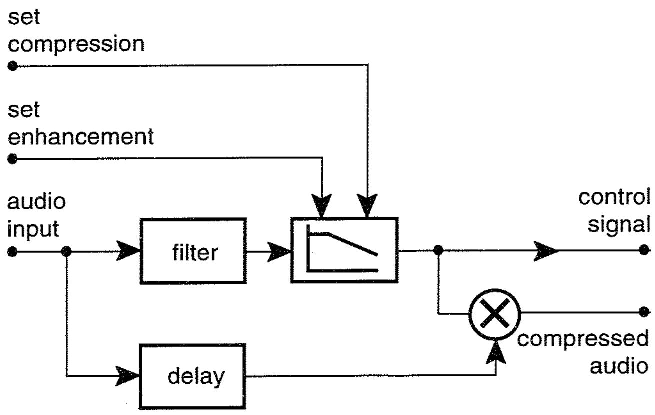


Fig. 8 - Basic block diagram to implement AMC.

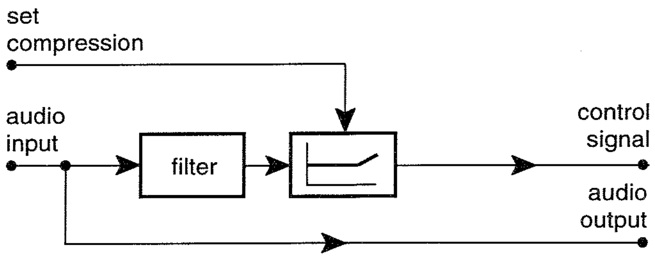


Fig. 9 - Basic block diagram to implement DAM.

3. EXPERIMENTAL WORK

A DSP system was developed to implement AMC for a 300 kW transmitter at the BBC's former HF transmitter site at Daventry.

A block diagram of the hardware of the development system is shown in Fig. 10. Whilst this development system involved the use of a Personal Computer (PC) at the transmitter to control the DSP card, it is envisaged that a final working system would use a stand-alone DSP card with an on board micro-controller. An example of a possible hardware arrangement for the final working system is shown in Fig. 11. The micro-controller would be responsible for providing an interface between the transmitting stations' control computer and the DSP board, probably by means of an RS232 serial link. Instructions would be passed down this link, interpreted by the micro-controller, and converted into values to be inserted in the DSP code to implement the requested compression settings.

The block diagram of the DSP code is shown in Fig. 12 *(overleaf)*. Signal level detection is carried out by rectification followed by filtering. The audio signal is rectified, as it is the modulus of the signal that is of interest.

The filtering is a little unusual because it is required to respond to rising signals with a time constant of somewhere between 0.3 ms and 5 ms (attack filtering), but then to decay with a much longer time constant — between 120 ms and 240 ms. The filtering was achieved by cascading a custom-written block which carried out the dual functions of peak hold and decay, with a digital implementation of a Butterworth low pass filter for the attack filtering.

The filtered output was converted to the control signal by applying the compression characteristic. This was also achieved by means of a custom-written block, which not only applied the required characteristic, but incorporated an enabling signal: it was important to inhibit the action of the compression whilst the transmitter was being switched on, and whilst it was tuning itself. Within the transmitter, the signals indicating these processes were combined, together with a signal from the station control computer, to form a single 'compression enable' signal.

In addition to being used to compress both the

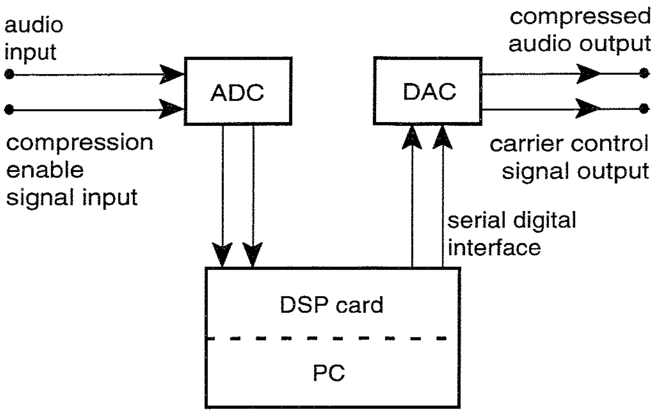


Fig. 10 - Hardware layout for the development system for DSP implementation of AMC and DAM.

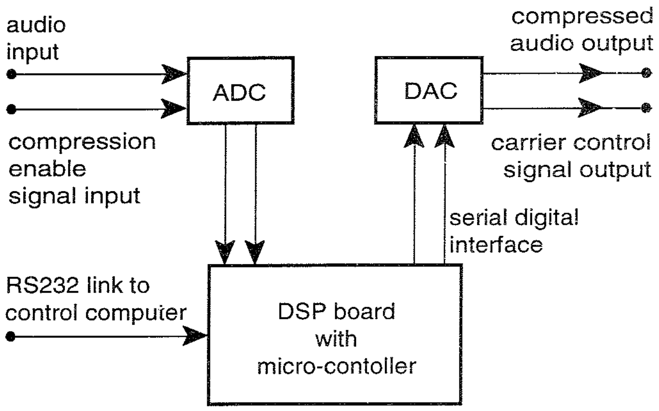


Fig. 11 - Example of hardware layout for the final system for DSP implementation of AMC and DAM.

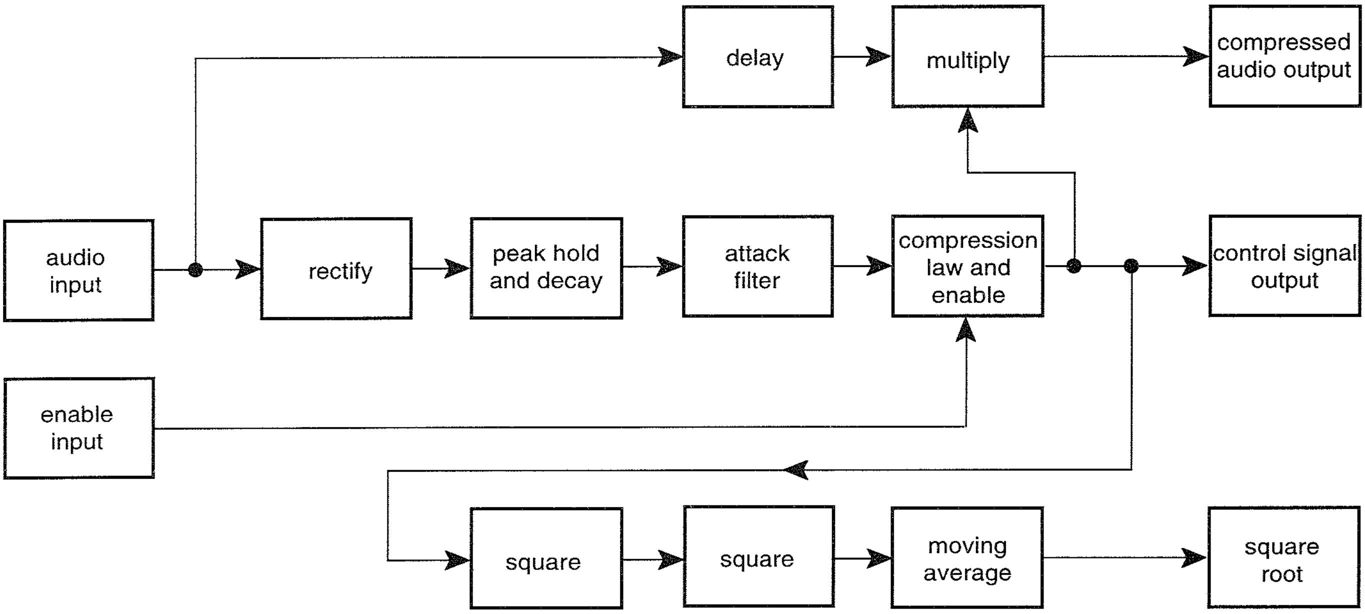


Fig. 12 - Detailed DSP layout diagram for implementing AMC.

audio and carrier components of the RF signal, the control signal was fed into the side chain (see Fig. 12). This side chain calculated the moving long term average power of the audio signal, which was used as mentioned above as a measure of average depth of modulation.

A program was written in 'C' for the PC, to provide an interface between the operator and the DSP code. The 'C' program requested the values of the various parameters (level of compression and enhancement, and attack and decay times), and wrote the appropriate values into the memory locations on the DSP board. The program also monitored the average depth of modulation if the enhancement mode was used, so that if it fell to a low level for more than a couple of minutes, the enhancement mode could be switched off.

A stand-alone DSP system was identified which would be suitable for use as the 'production' version, and featured full compatibility of the DSP code with the development system. The operation of the DSP is controlled by a micro-controller, and further code would be required to be written (as a replacement for the C program running on the PC) for a final system. One possible problem identified with this approach was its high unit cost.

4. RESULTS

The development system was initially set up to drive a laboratory signal generator which incorporated a modulator. Although apparently very different from a 300 kW transmitter, only the signal levels that were required to drive it differed. This allowed all of the functions of the system to be tested on the bench and confirmed that it was working as intended.

The system was next installed temporarily in a 300 kW transmitter at the BBC's former HF transmitter site at Daventry.

This system was used to broadcast a sample programme on a test frequency. The results of this were recorded by BBC Monitoring at Caversham. During this programme, various combinations of compression and enhancement were selected, and each was alternated with a period of uncompressed programme.

The only noticeable effects observed on the recorded signal were:

i) an audible click, which occurred when the compression was switched on or off, and

ii) a slightly different quality to the percussive speech sounds, only noticeable under critical listening conditions.

The first of these was due to the location of the enabling signal and would not normally occur under operational conditions. This problem could easily be cured by implementing the enabling signal prior to the filtering. The second problem was thought to be due to the rather short time constants which were used for this test, which could easily be adjusted.

5. CONCLUSIONS AND RECOMMENDATIONS

The feasibility tests carried out show that it is entirely possible to use the DSP system to implement and control compression algorithms for certain AM transmitters. Being an all digital solution, the DSP system is likely to be more rugged, reliable and flexible. The control of the compression could be made much more sophisticated, so that it included functions such as station energy management, and transmitter temperature control — indeed, it is only if this is done that the benefit of the DSP-based system will be readily seen, since the conventional implementation (hybrid analogue and digital) is adequate if all that is required is a fixed compression arrangement.

At the moment, the BBC is not planning to implement the DSP-based compression system because many of the transmitters for which it would be suitable have only recently been fitted with the conventional system. However it is an option which transmitter manufacturers should consider building into future generations of transmitter design. With the inevitable growth in the power of DSP systems, it may also be possible for the same DSP card to provide pre-correction for transmitter non-linearities, the addition of data signals, or other forms of signal processing at the transmitter.

6. ACKNOWLEDGEMENTS

The assistance of BBC Transmission in carrying out the tests of the DSP system on site at Daventry and BBC Monitoring for their assistance with the recordings is gratefully acknowledged.

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